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㊾ A single-mode-transmission optical fiber and a method of manufacturing the same.

㊼ A single-mode-transmission optical fiber comprising a core of a radius $\underline{a}$ having an arbitrary (not constant) refractive index distribution $n(r)$ in the radial direction $\underline{r}$, the index distribution being expressed by

$n^2(r) = n_1{}^2 \left\{ 1 - 2 \Delta_o f(r) \right\}$, and a cladding having a constant refractive index n_2, the radius $\underline{a}$ of the core being:

$$a < \frac{2.405 \lambda}{2 \pi Y n_2 \sqrt{2\Delta}} .$$

In these expressions, n_1 denotes the maximum refractive index of the core, λ denotes the transmission light wavelength,

$$\Delta = \frac{n_1{}^2 - n_2{}^2}{2 n_2} = \frac{n'_2}{n_2{}^2} \Delta_o ,$$

and the normalized frequency V is expressed by

$$V = \frac{2 \pi}{\lambda} a \, n_2 \sqrt{2 \Delta} .$$

Y is a solution Y in the case where X and Y are solutions of simultaneous equations:

$$\frac{\partial J_o}{\partial Y} = 0, \qquad \frac{\partial J_o}{\partial X} = 0$$

of a function which is expressed by:

$$J_o = \int_0^\infty \frac{1}{X^2 \, G^2 (YV)} \exp \left\{ - \frac{(\frac{r}{a})^2}{X^2 \, G^2 (YV)} \right\} .$$
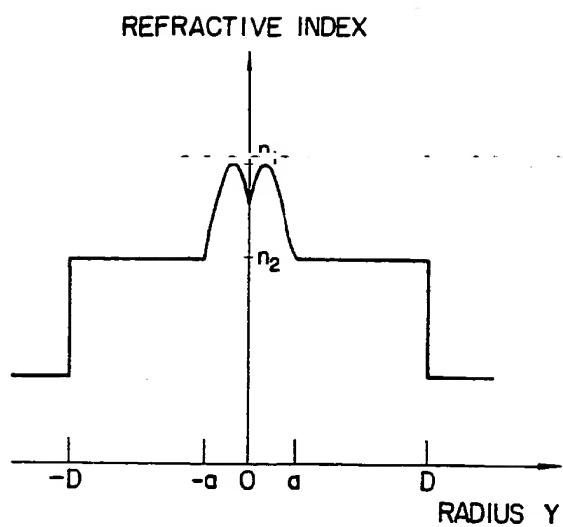
$$[1 - f(r) - \frac{Y}{X}]^2 \left\{ 1 - g(r) \right\}]^2 \, r \, dr$$

where

$$g(r) \begin{cases} = \\ \end{cases} \begin{matrix} 0 & O \leqq r < Xa \\ 1 & Xa \leqq r \end{matrix}$$

and

$$G(V) = \frac{1}{\sqrt{2}} (0.65 + 1.62 \, V^{-1.5} + 2.88 \, V^{-6}).$$

REFRACTIVE INDEX

n_1

n_2

$-D$ $-a$ O a D

RADIUS Y

A Single-Mode-Transmission Optical Fiber and a Method of
Manufacturing the Same

BACKGROUND OF THE INVENTION

This invention relates to a single-mode fiber and a
method of manufacturing the same. More particularly, it re-
lates to a single-mode optical fiber having a core whose
refractive index distribution is not constant but arbitrary
and a cladding whose refractive index is constant, and a
5   method of manufacturing the same.

At present, owing to the enhancement of the technolo-
gy of manufacturing optical fibers, the optical fibers have
come into the stage of practical use as communication trans-
mission lines. The optical fibers for communication use are
10   broadly classified into a multi-mode fiber and a single-
mode fiber. On account of problems in manufacture, many of
the optical fibers having heretofore been put into practi-
cal use are the multi-mode transmission fibers. However,
the single-mode fibers have a wider bandwidth than the
15   multi-mode fibers and can also be endowed with various
functions for many uses, so that future developments and
progress are expected.

It is well known in theory that the single-mode

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transmission fiber can be realized when, in a concentric construction which consists of a core having a constant refractive index n_1 and a cladding made of a material having a constant refractive index n_2 lower than the

5 refractive index n_1, the normalized frequency

$V = \frac{2\pi}{\lambda} a \sqrt{n_1^2 - n_2^2}$, where λ denotes the wavelength of transmission light and $\underline{a}$ denotes the radius of the core, fulfills the following relationship:

$$2.405 \geq \frac{2\pi}{\lambda} a \sqrt{n_1^2 - n_2^2} \qquad \qquad \ldots\ldots(1)$$

10 Known as being effective as methods of manufacture for realizing such optical fiber are a method in which a core, or thin glass layers to become a cladding and a core material is/are deposited on the inner wall of a substrate such as silica tube and the resultant

15 tube is drawn at a high temperature directly or after being put into a solid preform rod once, to produce a fine optical fiber, a method which is the rod-in-tube method and in which a rod to become a core material is inserted into a starting glass tube and the resultant tube is

20 drawn at a high temperature similarly to the above, and so on.

In particular, a method in which a thin glass film is formed on the inner wall of a silica tube or the like by the use of the chemical vapor deposition (CVD) process

and with a dopant introduced therein in order to attain a predetermined refractive index, a solid preform rod is formed and the preform rod is thereafter drawn at a high temperature is excellent as a method of manufacturing
5 an optical fiber of low transmission loss.

Since, however, the manufacturing process includes the steps of heating and collapsing, a dip is formed in the central part of the core of the optical fiber by the preferential evaporation of the dopant introduced
10 to the end of controlling the refractive index of the glass, and/or the rounding of the refractive index attributed to the diffusion of the dopant etc. occurs between the core and the cladding, so that the refractive index of the final optical fiber does not become the
15 ideal stepped index distribution which is constant in the core part. Accordingly, it becomes difficult to fabricate the single-mode fiber which is determined by Equation (1).

Especially in the single-mode fiber, the radius $\underline{a}$
20 and the difference of the squares of the refractive indices, $n_1^2 - n_2^2$, are very small, and hence, the controls thereof are attended with difficulties. It has heretofore been endeavored to render the refractive index of the core constant by removing the dip through the selection
25 of the material of the dopant and through a complicated

control of the distribution. In both the cases, however,

it is difficult to obtain the single-mode optical fiber

having desired characteristics as predetermined. Therefore,

the manufactured fiber does not execute the transmission

5 of light at the most effective service wavelength or

execute the multi-mode operation thereat to increase

the transmission loss. This results in the problem

that the yield of production is inferior.

SUMMARY OF THE INVENTION:

10   It is accordingly an object of this invention

to realize an optical fiber which carries out the single-mode

transmission reliably and to realize a method of manufacturing

a single-mode fiber which is of high yield.

      In order to accomplish the object, this invention

15 has realized a single-mode fiber upon finding out the

relationship among the refractive index distribution,

the wavelength and the core radius in the case where

the refractive index of the core of an optical fiber

varies complicatedly. Especially, it has the effect

20 that an optical fiber capable of the single-mode transmission

at 1.55 μm, which is known as the most effective wavelength

free from the transmission loss in case of transmitting

light with an optical fiber, can be readily realized.

      More specifically, the invention is characterized

25 in that, when the refractive index n(r) of an optical

fiber having an outer radius D at the radial distance $\underline{r}$ from the center of the optical fiber is expressed by:

$$n^2(r) = n_1^2 \left\{ 1 - 2 \Delta_o f(r) \right\}$$

where $\qquad 0 \leq f(r) < 1 \qquad$ for $\qquad 0 \leq r \leq a$

5 and $\qquad f(r) = 1$

and $\qquad n^2(r) = n_2^2 \qquad$ for $\qquad a < r \leq D$

and the refractive indices of a core have an arbitrary index distribution which is not constant, the radius $\underline{a}$ of the core is made:

10 $$a < \frac{2.405 \ \lambda}{2 \pi Y n_2 \ \sqrt{2 \Delta}} .$$

Here, λ denotes the wavelength of transmission light, n_2 the refractive index of a cladding, Δ the relative index difference or $\dfrac{n_1^2 - n_2^2}{2 n_2^2}$, n_1 the maximum value of the refractive indices of the core, and Y a value

15 which is determined as follows:

$$J_o = \int_0^\infty \frac{1}{X^2 \ G^2(YV)} \exp \left\{ - \frac{(\frac{r}{a})^2}{X^2 \ G^2(YV)} \right\}$$

$$\left[1 - f(r) - (\tfrac{Y}{X})^2 \left\{ 1 - g(r) \right\} \right]^2 r \ dr \cdot$$

where $\qquad g(r) = \begin{cases} 0 & 0 \leq r < X a \\ 1 & X a \leq r \end{cases}$

$$G(Y) = \frac{1}{\sqrt{2}} (0.65 + 1.62 \, V^{-1.5} + 2.88 \, V^{-6})$$

$$V = \frac{2\pi}{\lambda} \, a \, n_2 \, \sqrt{2\Delta} \, .$$

By solving the simultaneous equations of X and Y, $\frac{\partial J_o}{\partial X} = 0$

and $\frac{\partial J_o}{\partial Y} = 0$ of the above function, the value of Y is obtained.

5   The manufacture of the optical fiber having the
characterizing feature described above may be performed
as below. Thin layers of materials corresponding to
a cladding and a core or to a core are deposited by
the CVD process on the inner wall of a silica tube

10   or the like corresponding to a jacket or the cladding,
and the resultant tube is collapsed to form a solid
glass rod. Alternatively, an optical fiber glass rod
(hereinbelow, called the "preform") is formed by the
so-called rod-in-tube method. At the stage of the

15   preform, the refractive index distribution is measured
to evaluate the constants X and Y. The preform is
drawn from its one end at a high temperature so as
to establish a drawing ratio of $(\frac{d}{a})^2$ where $\underline{d}$ denotes
the radius of the core of the preform and $\underline{a}$ denotes

20   the radius of the core of the optical fiber intended
to be finally obtained.

    This invention is applicable to fibers of cores

having arbitrary index distributions. In addition,
the drawing ratio for obtaining a final fiber is determined
by measuring a refractive index distribution at the
time when a preform has been prepared. Therefore,
5 whereas time and expenses have heretofore been required
for attaining a predetermined value as the refractive
index of a preform, the present invention dispenses
with such steps. This facilitates remarkably the manufacture
of the single-mode optical fiber, and provides a very
10 effective measure for the reduction of cost of the product.

The above-mentioned and other features and objects
of this invention will become more apparent by reference
to the following description taken in conjunction with
the accompanying drawings.

15 BRIEF DESCRIPTION OF THE DRAWINGS:

Figures 1 and 2 are index profiles of an optical
fiber having a core of arbitrary refractive index distribution
and an optical fiber having a core of constant refractive
index distribution, respectively, for explaining the
20 principle of this invention,

Figure 3 is a diagram of a measured relative index
distribution of a preform in the manufacturing process of an optical
fiber according to this invention, and

Figure 4 is a diagram showing a measured result of the
25 relationship between the wavelength and the optical output
in an embodiment of the optical fiber according to this invention.

DESCRIPTION OF THE PREFERRED EMBODIMFNTS:

Figure 1 shows a model of the radial refractive index distribution of an optical fiber having a core whose refractive index distribution is not constant,

5 in order to elucidate the principle of this invention.

The refractive index distribution $n(r)$ in the radial direction $\underline{r}$ can be expressed as follows, for the core part or for $0 \leq r \leq a$:

$$n^2(r) = n_1^2 \left\{ 1 - 2\, \Delta_o\, f(r) \right\} \qquad \ldots (2)$$

10 where $f(r)$ is an arbitrary varying function of $0 \leq f(r) \leq 1$. For a cladding part or for $a < r \leq D$, it can be expressed by:

$$n^2(r) = n_1^2 \left\{ 1 - 2\, \Delta_o \right\} = n_2^2$$

Here, Δ is called the "relative index difference", and

$$\Delta = \frac{n_1^2 - n_2^2}{2\, n_2^2} = \frac{n_1^2}{n_2^2}\, \Delta_o \text{ holds.}$$

15 The electric field $E(r)$ of the dominant mode propagating through the optical fiber having such refractive indices fulfills approximately the following scalar wave equation:

$$\frac{1}{r} \frac{d}{dr}\left(r\, \frac{dE(r)}{dr} \right) + \left\{ k^2\, n^2(r) - \beta^2 \right\}\, E(r) = 0 \quad \ldots (3)$$

Here, $k = \frac{2\,\pi}{\lambda}$ denotes the wave number, and β the

20 propagation constant in the traveling direction of the electric field.

Figure 2 shows the radial refractive index distribution $n_s(r)$ of the so-called stepped index optical fiber whose ideal core has a constant refractive index and which is easy of theoretical analysis. This refractive index distribution is:

$$n_s^2(r) = n_{so}^2 \left\{ 1 - 2 \, \Delta_{so} \, g(r) \right\} \qquad \ldots (4)$$

where $g(r) = 0$ for $0 \leq r \leq a_s$

and $g(r) = 1$ for $a_s < r \leq D$.

Here, n_{so} denotes the refractive index of the core, which is constant. $\Delta_s = \dfrac{n_{so}^2 - n_2^2}{2 \, n_2} = \dfrac{n_1^2}{n_2^2} \, \Delta_{so}$ denotes the relative index difference, a_s denotes the radius of the core, and the other symbols are the same as in Equation (2).

Similarly to Equation (3), the electric field $E_s(r)$ of the dominant mode propagating through the stepped index optical fiber is expressed by:

$$\frac{1}{r} \frac{d}{dr} \left(r \, \frac{dE_s(r)}{dr} \right) + \left\{ k^2 \, n_s^2(r) - \beta_s^2 \right\} E_s(r) = 0$$

$$\ldots (5)$$

Here, β_s denotes the propagation constant of the stepped index optical fiber.

In order that these optical fibers shown in Figures 1 and 2 may have equivalent propagation characteristics, the following must hold on the basis of Equations (3) and (5):

$$E(r) = E_s(r)$$

$$\beta = \beta_s \qquad\qquad \Bigg\} \qquad\qquad \dots (6)$$

From Equations (3), (5) and (6), the following equation is obtained:

$$E_s(r)\left\{n^2(r) - n_s^2\right\} = 0 \qquad\qquad \dots (7)$$

Strictly the electric field $E_s(r)$ in Equation (7) can be expressed by the Bessel function. Since, however, the electric field distribution of the stepped index optical fiber is very similar to the Gaussian distribution, the electric field $E_s(r)$ can be approximated as follows:

$$E_s(r) = \frac{1}{\omega_s} \exp\left(-\frac{r^2}{2\,\omega_s^{\,2}}\right) \qquad\qquad \dots (8)$$

Here, ω_s denotes a mode spot size which can be approximately expressed as follows:

$$\omega_s = a_s\, G(V_s) \qquad\qquad \dots (9)$$

$$G(V_s) = \frac{1}{\sqrt{2}}\,(0.65 + 1.62\, V_s^{-1.5} + 2.88\, V_s^{-6})$$

$$V_s = \frac{2\pi}{\lambda}\, a_s\, n_2\, \sqrt{2\,\Delta_s}$$

Accordingly, the optical fiber having the arbitrary index distribution as shown in Figure 1 can be converted into the equivalent, stepped index optical fiber. Here, letting $\underline{a}$ denote the radius of the core having the arbitrary refractive indices and $V = \frac{2\pi}{\lambda}\, a\, n_2\, \sqrt{2\Delta}$, the equivalent

core radius a_{SE} and the normalized frequency V_{SE} thereof can be expressed with constants X and Y, as follows:

$$\left. \begin{array}{l} a_S = a_{SE} = X\,a \\[2mm] V_S = V_{SE} = Y\,V \end{array} \right\} \qquad \ldots(10)$$

5   Accordingly, the evaluation of the equivalent stepped index distribution results in evaluating the constants X and Y. In order to evaluate X and Y, Equation (7) is substituted into Equations (8) - (10), and the resultant equations are arranged, whereupon X and Y which minimize

10 the following equation may be finally found by the optimization method for X and Y.

$$J_O = \int_0^\infty \frac{1}{X^2\,G^2(YV)}\,\exp\left\{-\frac{(\frac{r}{a})^2}{X^2\,G(YV)}\right\}$$

$$\left[1 - f(r) - (\tfrac{Y}{X})^2\left\{1 - g(r)\right\}\right]^2 r\,dr \quad \ldots(11)$$

The minimum values of X and Y can be uniquely determined

15 by solving the following simultaneous equations:

$$\frac{\partial J_O}{\partial X} = 0, \qquad \frac{\partial J_O}{\partial Y} = 0 \qquad \ldots(12)$$

Accordingly, in order that the optical fiber having the normalized frequency $V_{SE} = Y\,V$ in Equation (10) may effect the single-mode transmission, the following

20 relationship may be met:

$$2.405 \geq Y\,V = Y\,\frac{2\,\pi}{\lambda}\,a\,n_2\,\sqrt{2\Delta}$$

That is,

$$a \leq \frac{2.405 \ \lambda}{2 \pi \ Y \ n_2 \sqrt{2\Delta}}$$

Now, there will be described an example of a single-mode

fiber according to this invention manufactured on the

5 basis of the principle described above.

On the inner wall of a silica tube made of SiO_2

and to become a cladding, thin layers made of 4.2 mol-%

of GeO_2 and 95.8 mol-% of SiO_2 and to become a core

were formed by the CVD process. The resultant tube

10 was heated and collapsed to form a solid preform. Since

these manufacturing steps have heretofore been well known,

the detailed explanation will be omitted.

The preform had an outer diameter (2D) of 13 mm, and

it was sliced at an axial thickness of approximately

15 80 μm to form a small disc. The disc was observed

with an interference microscope, to measure the refractive

index distribution of the core in the radial direction.

Figure 3 shows the result of the measurement, in

which the axis of abscissas represents the distance

20 in the radial direction and the axis of ordinates the

refractive index. In the figure, a curve 1 indicates

actually-measured values in terms of the relative index

difference, while a curve 2 indicates an equivalent,

stepped index distribution which has a propagation

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characteristic equivalent to the curve 1 and which
has been obtained on the basis of the foregoing principle.

It is understood that the refractive indices of
the actual measurement 1 form a complicated index distribution
5   in which a rounding appears around the core and the
cladding and in which a deep dip appears in the central
part.

The preform is drawn at a high temperature and
finally becomes an optical fiber. The index distributions
10   of the preform and the optical fiber are scarcely different,
and merely the index distribution is compressed in
the radial direction in the optical fiber. This is
because the index distribution is almost determined
by the process up to the preform and becomes stable.
15   In the heating and drawing step, the index distribution
undergoes no appreciable substantial change.

Accordingly, the foregoing values X and Y can be
obtained when the preform has been finished.

It was immediately seen that the core radius (d)
20   of the preform was about 300 μm and that the maximum
relative index difference Δ was about 0.4 %. The index
distribution obtained indicated the function f(r) in Equation (2)
and Equation (11), and when the evaluated result was
substituted into Equations (11) and (12), X = 0.95
and Y = 0.79 were calculated. Thus, the equivalent

core radius (d_s) in the equivalent, stepped index preform

became d_s = 285 μm from d_s = X d = 0.95 x 300, while

the relative index difference Δ_s was evaluated from

$\Delta_s = (\frac{Y}{X})^2 \Delta$ to be $\Delta_s = 0.277$ %.

5 From the preform, there was produced a single-mode

fiber whose transmission wavelength was a semiconductor

laser wavelength λ = 0.83 μm deemed to be the most effective

wavelength in the optical transmission and which had

a normalized frequency V_s = 2.08 in order to lessen

10 the micro-bending loss. To this end, the core radius

(a_s = X a) of the equivalent, stepped index optical

fiber was evaluated to be a_s = 2.53 μm by substituting

the foregoing values into:

$$a_s = \frac{V_s \lambda}{2 \pi n_2 \sqrt{2 \Delta_s}}$$

15 Accordingly, in order to obtain the desired optical

fiber from the preform, a

$$\text{drawing ratio} = (\frac{d_s}{a_s})^2 = (\frac{d}{a})^2$$

might be established. In other words, the drawing ratio

might be made $(\frac{2 \pi n_2 \; Y \; X \; d \; \sqrt{2\Delta}}{2.405 \; \lambda})^2$. The substitution of

20 the numerical values resulted in about 12,705 times. At

this time, the outside diameter of the optical fiber

(the diameter of the cladding) was 115 μm.

Figure 4 shows the measured result of the relationship between the used light wavelength λ (μm) and the optical output (μW) in the case of the optical fiber according

5   to the example.

A method of the measurement was such that the optical fiber of about 40 cm produced by the example was arranged to be rectilinear, that incoherent light was caused to enter an input end of the optical fiber

10 by the use of an objective lens having a magnification of about 20, that an optical filter capable of varying a wavelength to pass therethrough was situated between the lens and a light source, and that light emerging from the other end of the optical fiber was measured

15 with a photomultiplier.

Now, it will be proved from the measured result that, in spite of having the complicated index distribution, the fiber of the present example had the characteristic as previously designed, in other words, the normalized

20 frequency V becoming a value close to 2.08 at the wavelength λ = 0.83 μm.

As apparent from the experimental result, the optical output obtained exhibits an abrupt change near a wavelength λ = 0.7 μm.   This appears because the

25 secondary mode, LP_{11} mode is excited along with the

dominant mode at light wavelengths of and below 0.7 μm.

Since the LP_{11} mode is excited, the apparent number

of aperture increases and the quantity of light entering

the optical fiber increases. From the above fact, the

5 abrupt change indicates the cutoff wavelength (λ_c) of

the secondary mode LP_{11}. The reason why the waveform

becomes complicated is that it appears as the product

between the mode transmission characteristics and the

spectral component of the incoherent light source used

10 as the light source. It can be easily conjectured

that, if a coherent light source whose wavelength is

variable can be used, the waveform will change in a

stepped fashion with the boundary at the cutoff wavelength λ_c.

In the stepped index fiber, the secondary mode

15 LP_{11} appears when the value of the normalized frequency

V_s is 2.405 or greater. In the optical fiber of the

above example, the wavelength λ_c which gives this V_s value

is approximately 0.7, which is understood to substantially

correspond to the case of the stepped index fiber. Accordingly, from

20 $$2.405 = \frac{2\pi}{0.7} a_s \sqrt{n_1^2 - n_2^2},$$

there holds $2\pi a_s \sqrt{n_1^2 - n_2^2} = 2.405 \times 0.7 = 1.6835$.

Therefore, the value of the normalized frequency V

at the time when the light of the wavelength $\lambda = 0.83$ μm

is used becomes approximately 2.05, and it is understood

to become close to the aimed value 2.08 of the design

described previously.

As set forth in the foregoing example, according

to this invention, an optical fiber having a desired

5 single-mode transmission characteristic as predetermined

can be readily realized even when the refractive index

distribution of its core varies complicatedly, and

complicated steps for the control of refractive indices

in the manufacturing process of a preform as have heretofore

10 been required are dispensed with, which in turn reduces

the production cost of the optical fiber.

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CLAIMS:

1. A single-mode optical fiber comprising a cladding which has a constant refractive index n_2, and a core of a radius $\underline{a}$ which is surrounded by said cladding, characterized in that the refractive indices of the core are greater than said

5   refractive index n_2 and have in the radial direction $\underline{r}$ an arbitrary index distribution $n(r)$ expressed by

$$n^2(r) = n_1^2 \left\{ 1 - 2 \, \Delta_o \, f(r) \right\} \quad \text{(where } 0 \leq f(r) \leq 1\text{)},$$

said radius $\underline{a}$ of said core being:

$$a < \frac{2.405 \, \lambda}{2 \, \pi \, Y \, n_2 \, \sqrt{2\Delta}}$$

10 X and Y being solutions of simultaneous equations of:

$$\frac{\partial J_o}{\partial X} = 0, \qquad \frac{\partial J_o}{\partial Y} = 0$$

of a function which is expressed as follows, by letting n_1 denote a maximum refractive index of said core and λ denote a transmission light wavelength thereof, so

15 that the relative index   difference thereof is denoted by

$$\Delta = \frac{n_1^2 - n_2^2}{2 \, n_2^2} = \frac{n_1^2}{n_2^2} \, \Delta_o \quad \text{and that the normalized frequency is}$$

denoted by $V = \frac{2 \, \pi}{\lambda} \, a \, n_2 \, \sqrt{2\Delta}$:

$$J_0 = \int_0^\infty \frac{1}{x^2 \, G^2(YV)} \, \exp\left\{ - \frac{(\frac{r}{a})^2}{x^2 \, G^2(YV)} \right\}$$

$$[1 - f(r) - (\frac{Y}{X})^2 \{1 - g(r)\}]^2 \, r \, dr$$

where
$$g(r) = \begin{cases} 0 & 0 \leq r < X\,a \\ 1 & X\,a \leq r \end{cases}$$

5 and

$$G(V) = \frac{1}{\sqrt{2}}(0.65 + 1.62 \, V^{-1.5} + 2.88 \, V^{-6}).$$

2. A method of manufacturing a single-mode optical fiber wherein a preform is formed and is drawn at a high temperature into the optical fiber, characterized by measuring the refractive index distribution of the preform after completion

10 thereof, solutions X and Y of simultaneous equations of:

$$\frac{\partial J_0}{\partial X} = 0, \qquad \frac{\partial J_0}{\partial Y} = 0$$

being obtained as to a function which is expressed as follows, by letting f(r) denote said refractive index distribution and d the radius of the core of said preform:

15

$$J_0 = \int_0^\infty \frac{1}{x^2 \, G^2(YV)} \, \exp\left\{ - \frac{(\frac{r}{d})^2}{x^2 \, G^2(YV)} \right\}$$

$$[1 - f(r) - (\frac{Y}{X})^2 \{1 - g(r)\}]^2 \, r \, dr$$

where $\quad g(r) = \begin{cases} 0 & 0 \leq r \leq X\,d \\ 1 & X\,d \leq r \end{cases}$

and

$$G(V) = \frac{1}{\sqrt{2}} (0.65 + 1.62\ V^{-1.5} + 2.88\ V^{-6}),$$

and making the drawing ratio greater than

5
$$\left(\frac{2\ \pi\ n_2\ Y\ X\ d\ \sqrt{2\Delta}}{2.405\ \lambda}\right)^2$$

(where n_2 denotes a maximum refractive index of the
preform core, and Δ a relative index difference).

3. The method of claim 2, characterized in that the
step of forming said preform comprises forming a material
10 to become a core part, on an inner wall of a silica tube
by the CVD process, and heating the resultant silica tube
into a solid glass rod.

4. The method of claim 2, characterized in that the
step of forming said preform comprises forming materials to
15 become a cladding part and a core part, on an inner wall of
a silica tube successively by the CVD process, and heating
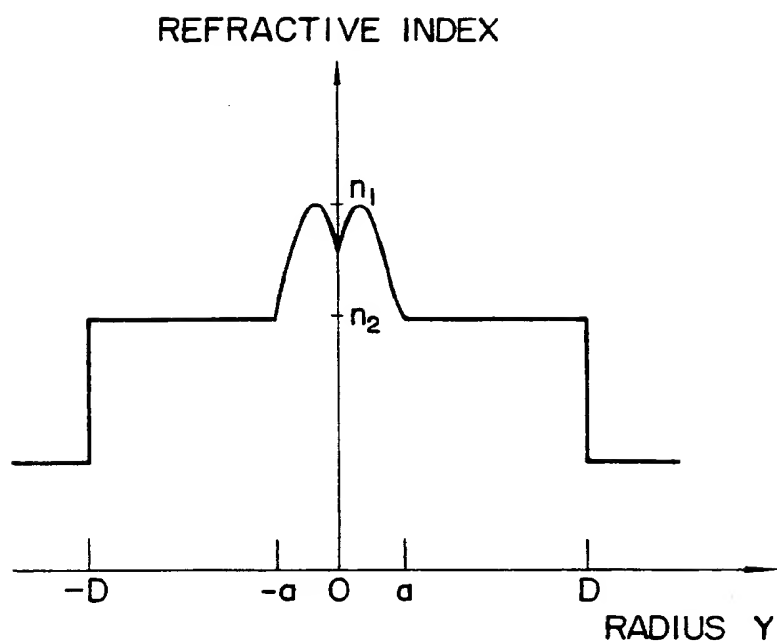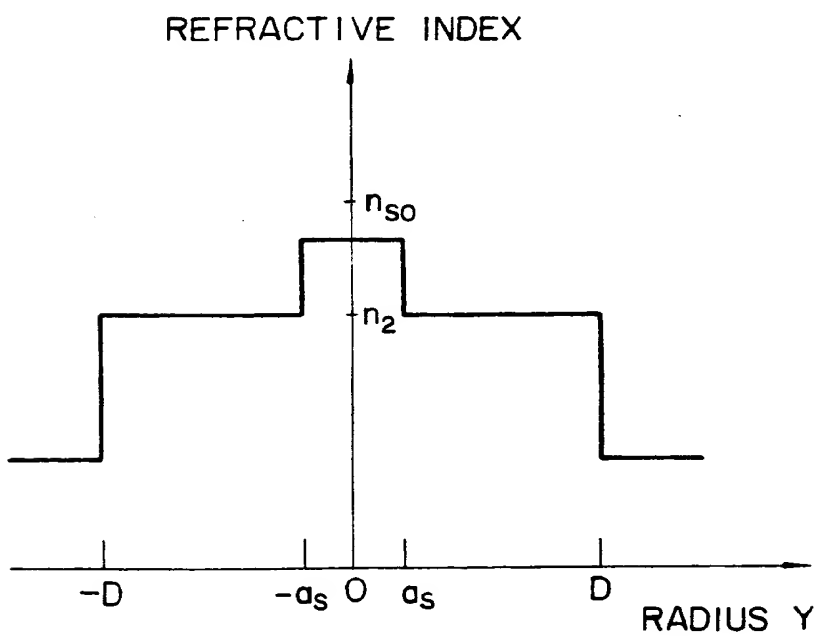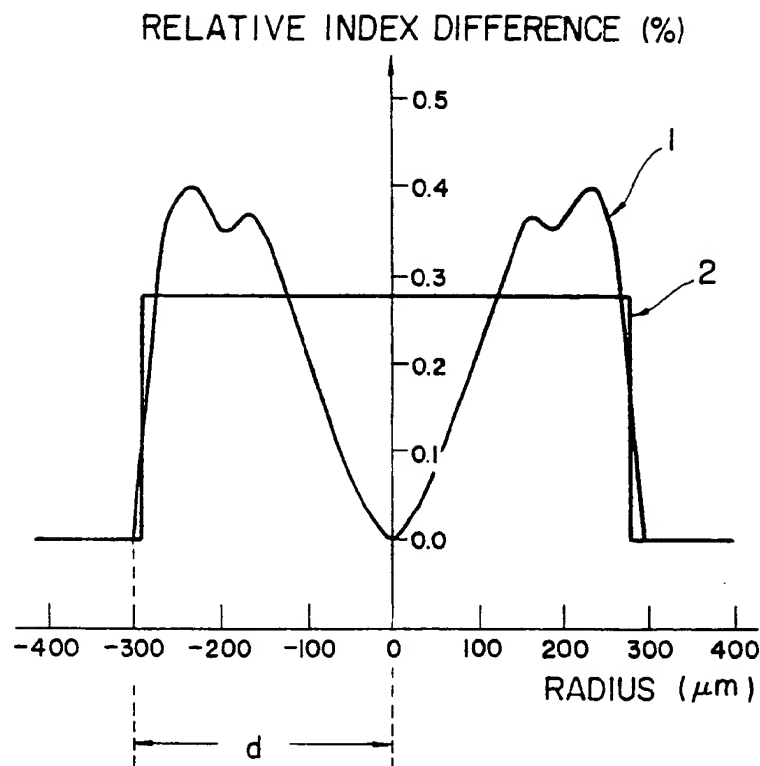the resultant silica tube into a solid glass rod.

FIG. 1

REFRACTIVE INDEX

n_1

n_2

-D   -a O a   D

RADIUS Y

FIG. 2
PRIOR ART

REFRACTIVE INDEX

n_{so}

n_2

-D $-a_s$ O a_s D

RADIUS Y

FIG. 3

RELATIVE INDEX DIFFERENCE (%)

FIG. 4

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
	PHYSICS AND CHEMISTRY OF GLASSES, Vol. 21, No. 1, February 1980 S.R. NORMAN "Fabrication and Evaluation of Single Mode Fibres" page 53 to 57 * page 54, above right *	1,2
	REVIEW OF THE ELECTRICAL COMMUNICATION LABORATORIES, Vol. 26, No. 3/4, March/April 1978, A. KAWANA et al. "Fabrication of Low Loss Single-Mode Fiber" pages 468 to 475 * fig. 2 *	3,4
A	US - A - 4 089 586 (W.G. FRENCH et al.) * complete document *	
A	OPTICAL AND QUANTUM ELECTRONICS, Vol. 10, No. 4, 1978 W.A. GAMBLING et al. "Wave Propagation in a Single-Mode Fibre with Dip in the Refractive Index" pages 301 to 309	

DOCUMENTS CONSIDERED TO BE RELEVANT

CLASSIFICATION OF THE APPLICATION (Int. Cl.³)

G 02 B   5/14

TECHNICAL FIELDS SEARCHED (Int. Cl.³)

C 03 B   17/02
G 02 B   5/14

CATEGORY OF CITED DOCUMENTS

X: particularly relevant
A: technological background
O: non-written disclosure
P: intermediate document
T: theory or principle underlying the invention
E: conflicting application
D: document cited in the application
L: citation for other reasons

&: member of the same patent family, corresponding document

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Berlin	25-05-1981	FUCHS

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